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Aerodynamic and Aeroelastic Applications of a Parallel, Multigrid, Unstructured Flow Solver

Sriram and Antony Jameson
Department of Aeronautics and Astronautics
Stanford University, Stanford, CA 94305-3030

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AERODYNAMIC AND AEROELASTIC APPLICATIONS OF A PARALLEL MULTIGRID UNSTRUCTURED FLOW SOLVER

Sriram *and Antony Jameson †
Department of Aeronautics and Astronautics
Stanford University, Stanford, CA 94305-3030

Introduction

Numerical experiments to analyze fluid flow problems are finding increasing use in engineering environments. While refined computational tools are useful to obtain detailed information about flow physics, approximations based on linear theory are invaluable during the conceptual stages of design. Rapid turnaround time for these computations coupled with the relatively lower level of expertise required by the end-user makes these methods extremely attractive for use in an industrial environment. Growth in computing power and development of efficient numerical algorithms have enabled the use of non-linear approximations to the flow equations to be incorporated in the design cycle. While routine computations using RANS based solvers are gaining momentum, the lack of completely automated grid generation tools and the incomplete understanding of the phenomenon of turbulence plagues rapid growth of this technology. Inviscid assumptions on the governing flow equations have helped in the development of grid generation tools and flow solution methods which can be routinely used in an industrial environment. Finite Volume[1], Finite Element[23] and Finite Difference methods[4] to numerically solve the Euler equations have reached a fairly reasonable level of sophistication for both structured and unstructured meshes. Generation of multi-block structured grids around complete aircraft configurations, while seemingly tedious, is still a tractable problem[56]. Unstructured grid generation methods have become more robust in the last decade enabling inviscid and viscous approximations to the flow field around complex geometries like that of a full aircraft in landing configuration[78910]. Industrial strength unstructured viscous mesh generators are an ongoing quest. Under these circumstances, neglecting the effect of viscosity and solving for the Euler equations seems to provide the flexibility of handling complex geometries and the advantages of robust numerical methods[1112].

In this paper we discuss the applications of an unstructured flow solver to compute the transonic flow around a complete aircraft and in predicting the flying shape of upwind sails. Significant improvements have been made to a previously well documented computational tool, AIRPLANE[13], to enable the computation of the transonic flow around a complete aircraft configuration to be performed in approximately 10 minutes using 16 processors of a 1.4 Ghz Athlon cluster running RedHat Linux 2.2.16. Aeroelastic computations to predict the flying shape of sails can be obtained in around 30-40 minutes using 8 processors of an SGI origin 2000. Parallel implementation of the baseline multigrid flow solver is discussed in the next section and the aeroelastic computational methodology and its components will be the discussed in the subsequent section. Sample computations of the transonic flight of the MD-11 and the Lockheed S3-A are shown the concluding section. Moreover, the code has been extended to treat incompressible flows by the method of artificial compressibility and it has been coupled to a structural analysis to perform aeroelastic calculations for sails of high performance yachts. The flying shape a head and main sail combination that is representative of what is used in the Americas Cup class of boats is shown the concluding section.

Aerodynamic computations of complete aircraft configurations

Using an unstructured grid generator, a series of non-nested meshes to be used in the multigrid cycle is generated. Later, in a pre-processing step, the nodes and edges of each mesh are distributed among the available processors while balancing the load among the processors. The weighting factors used to transfer the solution, aggregate the residuals and interpolate the corrections for the multigrid cycle are also computed in the pre-processing step. A critical improvement is the use of an octree based search routine. This enables the pre-processing step, including the computation of the transfer co-efficients, of a fine mesh with 445,000 nodes and three levels in the multigrid cycle to be completed in under 10 minutes on a 1.4 Ghz Intel processor with 1Gb RAM. Parallel implementation of this step is being studied and will become a necessity for viscous applications and for aeroelastic computations where the mesh is modified during each iterative cycle of aerelastic procedure. Parallel implementation

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*Doctoral Student
†Professor, Stanford University

of the multigrid flow solver will be discussed in detail in the final version of the paper.

Aeroelastic Computations to predict the Flying Shape of Upwind Sails

The parallel multigrid solver discussed in the previous section was modified using the idea of artificial compressibility to analyze steady, incompressible flows. Modifications to the inlet boundary condition so as to simulate the boundary layer profile over a free-surface was incorporated along with load transfer, finite element structural calculations and mesh movement strategies to predict the deflected shape of the main sail and head and main sail combinations. An iterative method which transfers the pressure loading to the structure and the deflections to the computational fluid mesh is used to obtain the steady deflected shape of the sails. The Finite Element computations were performed using the commercial package, Nastran. The sailcoth was modeled with quadrilateral orthotropic membrane elements with fixed translational degrees of freedom along the mast of the main sail and points of attachment of head sail to the rig. The deflections from the structural calculations were transferred to the computational fluid mesh using a 'spring analogy' technique. Alternate strategies which attempt to solve the elasticity equations are also being studied. Typical computational times for the aeroelastic calculations vary from 30 minutes for a mail sail alone and about 45 minutes for a head and mail sail combination, both computations were performed on a SGI Origin 2000 using 8 processors.

Results

Simulation of Transonic Flight of Complete Aircraft Systems

The transonic cruise condition of the MD-11 was analyzed with the compressible flow solver. The Mach number for this computation was 0.825 and the angle of attack was 2.5^o. The density contours are shown in Fig. 1. The Mach number contours for the cruise flight of the LockHeed S3-A at a Mach Number of 0.7 and an angle of attack of 7^o is shown in Fig. 2.

The results shown are for a single grid calculation. Results from a multigrid calculation will be shown in the final version of the paper.

Head and Main sail combination for the Americas Cup

A head and main sail combination representative of the sails used in the Americas Cup was analyzed using the aeroelastic package. Leeward and Windward side pressure distributions are shown in Fig. 3 and Fig. 4 respectively. Three computational grids were used in a W-cycle with the finest mesh containing 414,200 nodes. 100 multigrid cycles were required to obtain a converged solution. 4000 quadrilateral elements were used in finite element structural mesh of

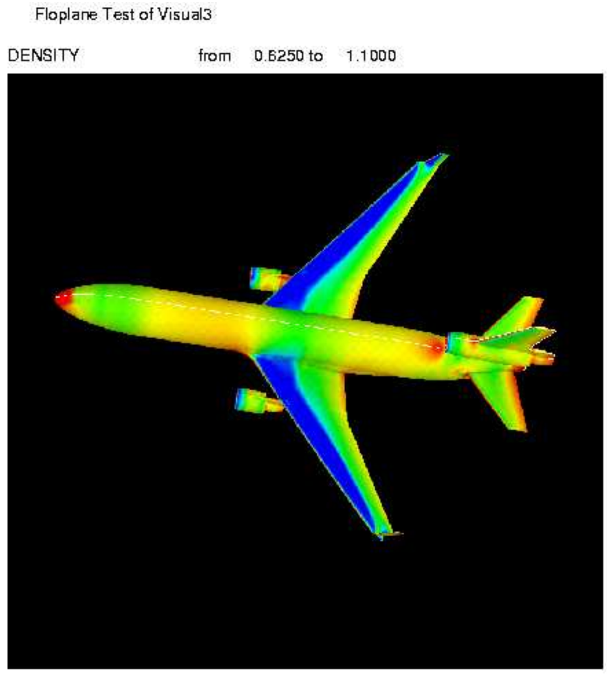

Fig. 1 Density contours on the upper surface of the MD11 at a Mach Number of 0.825 and Angle of Attack of 2.5^o.

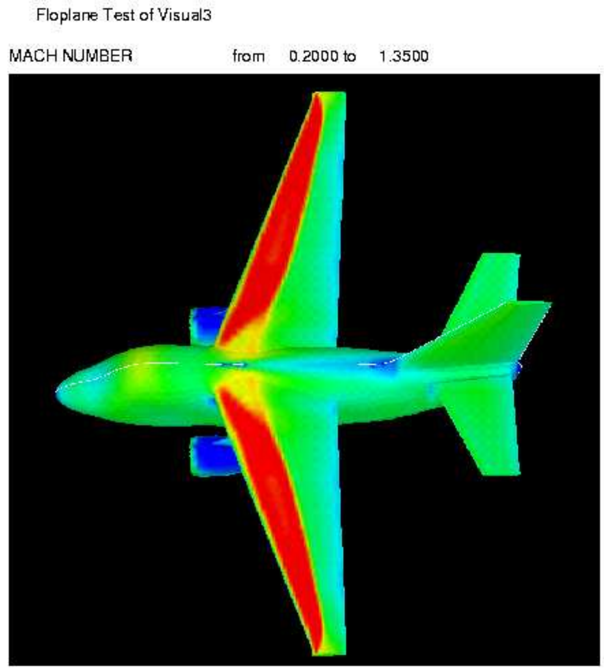

Fig. 2 Mach number contours on the upper surface of the S3-A at a Mach Number of 0.7 and Angle of Attack of 7^o.

the main sail and 1860 on the head sail. The material properties of dacron were used to model the sail cloth. The presence of battens and tension cables and other forces from the rig were neglected in the structural model. 3-4 aeroelastic iterations were required to obtain the deflected shape.

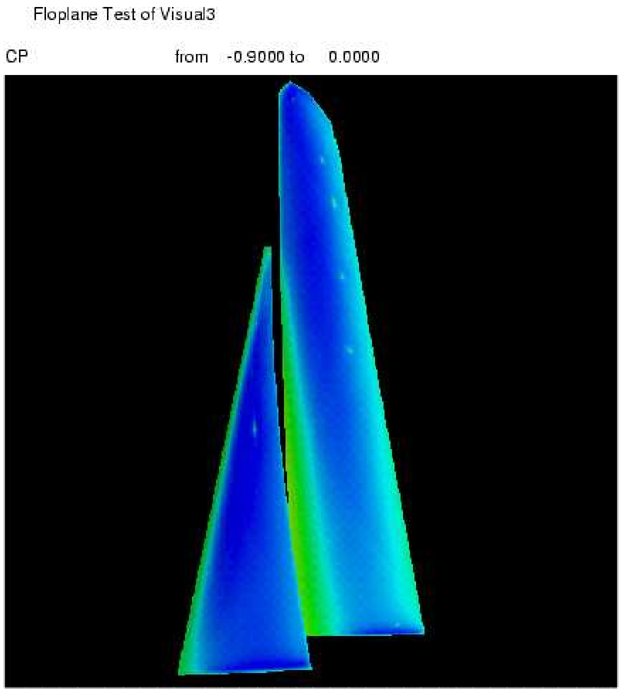

Fig. 3 Pressure contours on the Leeward side

Future directions of Research

The eventual aim of this effort is to develop an automated computational tool to design wing, wing-body, complete aircraft geometries and upwind sail configurations. Reductions in wave drag for transonic aircrafts and induced drag and rolling moment for sail configurations are possible areas of applications of this design process.

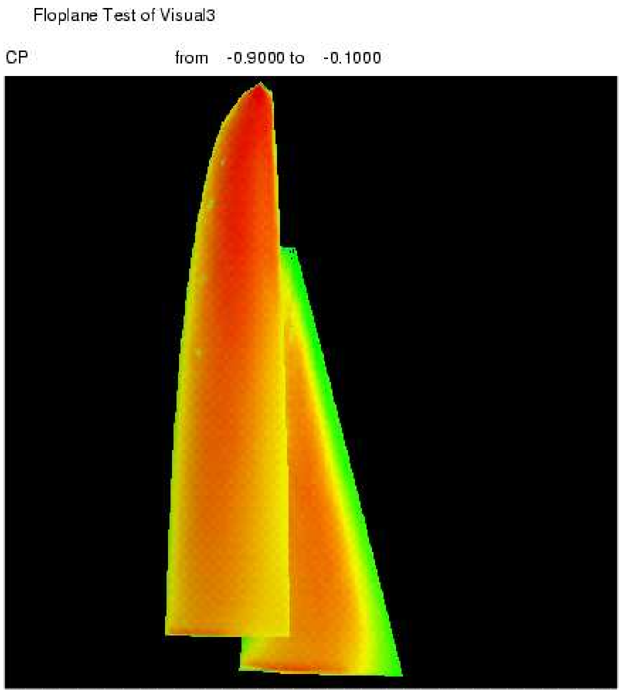

Fig. 4 Pressure contours on the Windward side

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